



B_s and Λ_b Lifetimes and BRs at the Tevatron

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⊕ $BR(B_s \rightarrow D_s^{(*)} D_s^{(*)})$

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Other talks:

⊕ $BR(B_s \rightarrow \mu \mu)$ limits

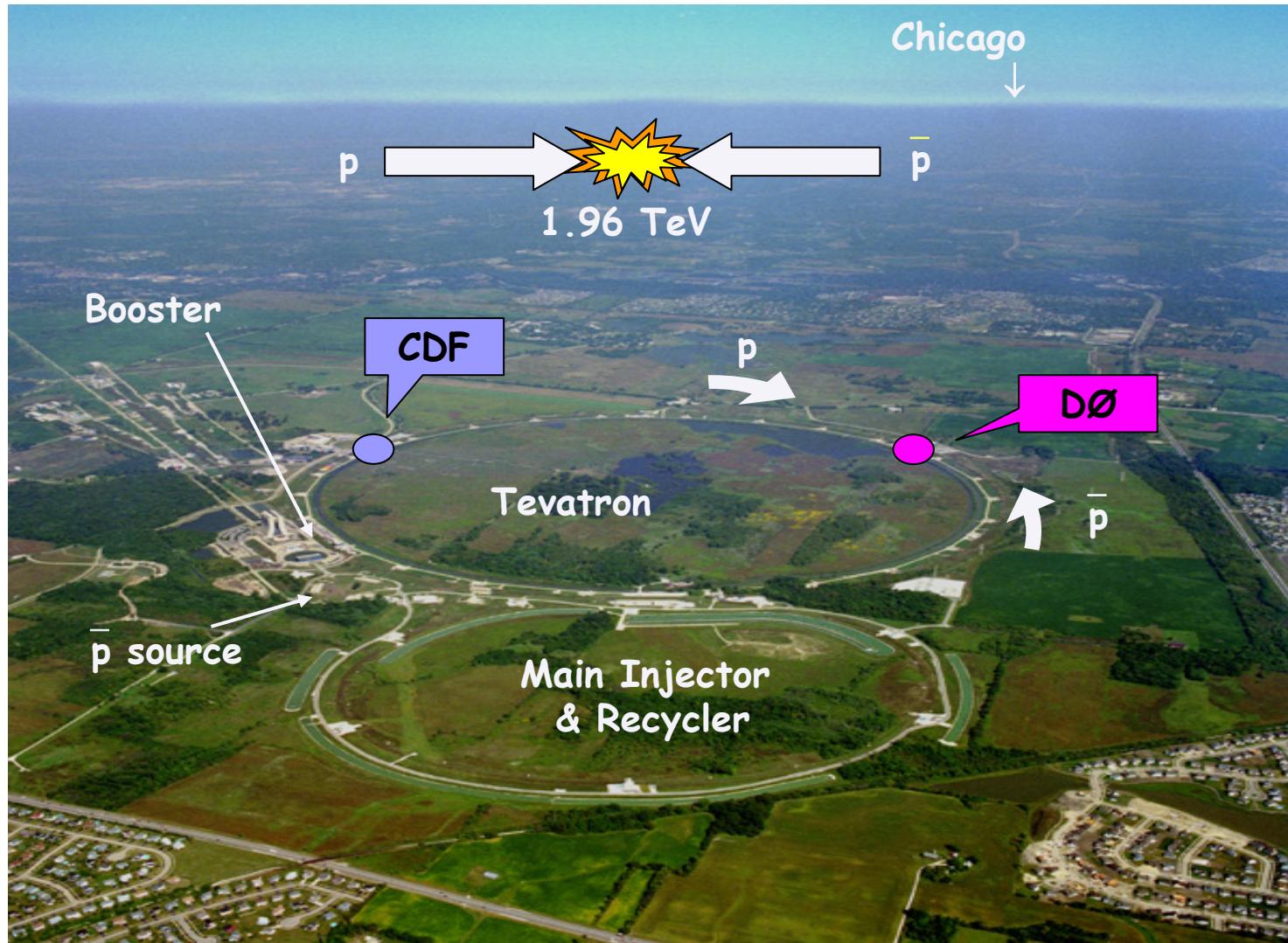
[[Talk by Cheng-Ju Lin](#)]

⊕ $\Delta\Gamma$ in $B_s \rightarrow J/\Psi \phi$

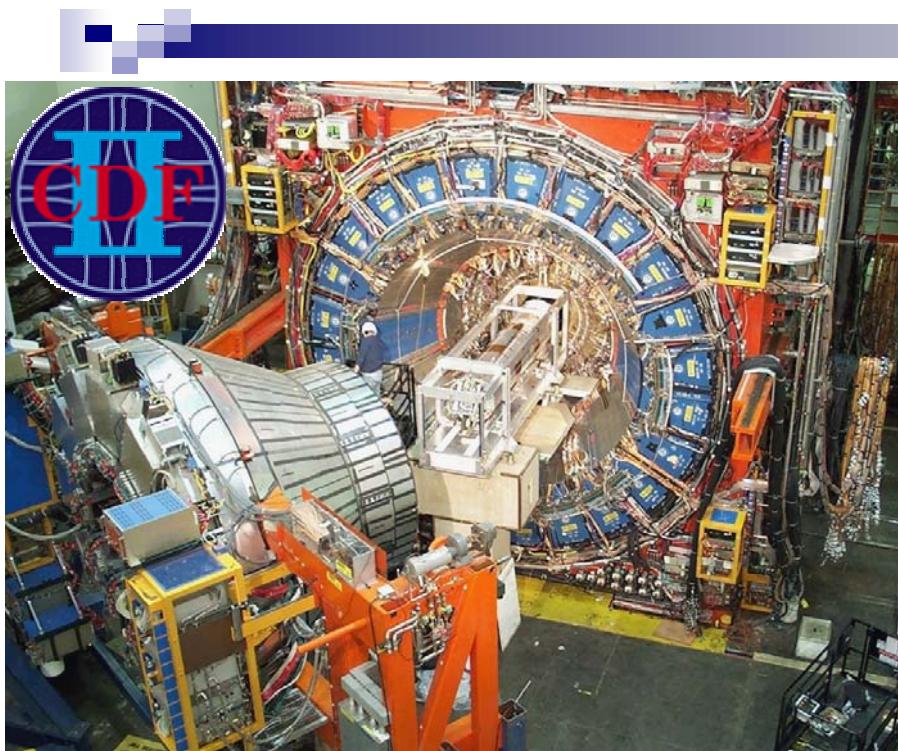
[[Talk by Avdhesh Chandra](#)]

⊕ Summary

The Tevatron



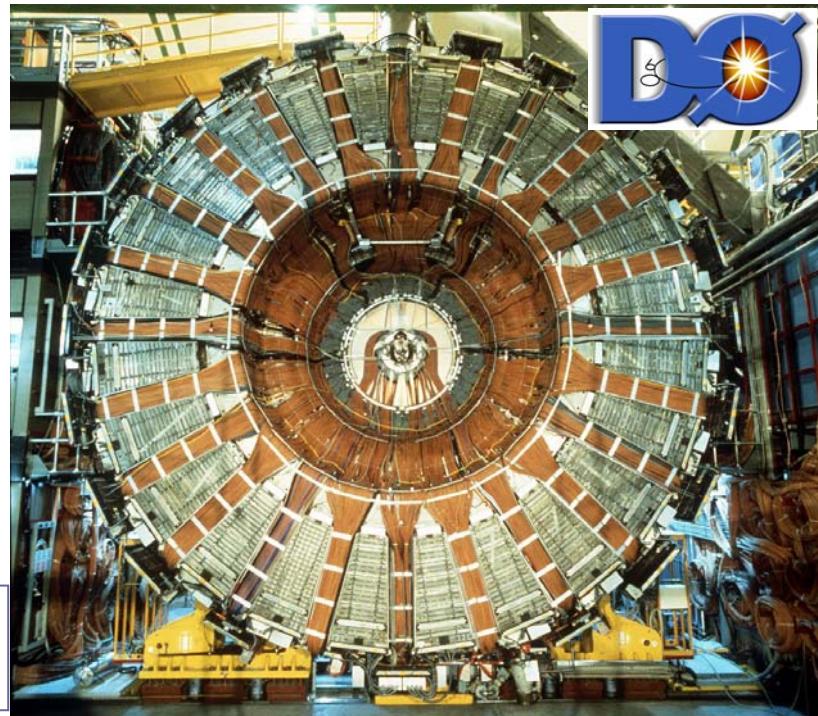
CDF and DØ Detectors in Run 2



L2 trigger on displaced vertices
Excellent tracking resolution
Good low momentum PID

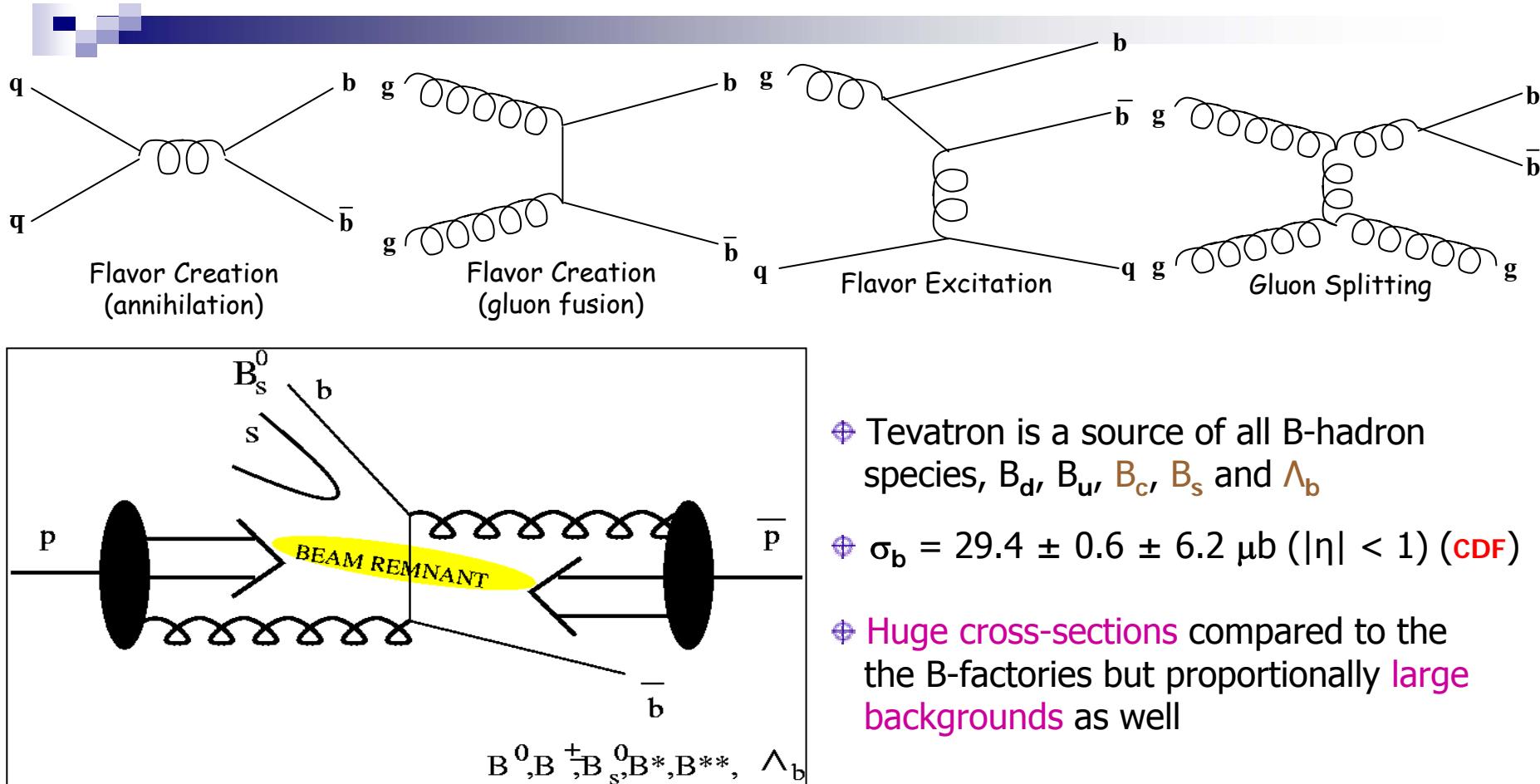
Both detectors

- ⊕ Silicon microvertex tracker
- ⊕ Solenoid
- ⊕ High rate trigger/DAQ
- ⊕ Calorimeters and muons



Good electron, muon ID and acceptance
Excellent tracking acceptance $|\eta| < 2\text{-}3$

B Production at Tevatron



Since $\sigma(bb) \ll \sigma(pp)$ \Rightarrow Events have to be selected with specific triggers

Trigger requirements: large bandwidth, background suppression, deadtimeless

Triggers for B Physics

Single-/Di-lepton (CDF/D \emptyset)

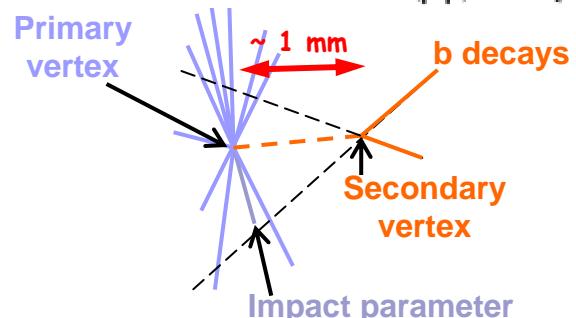
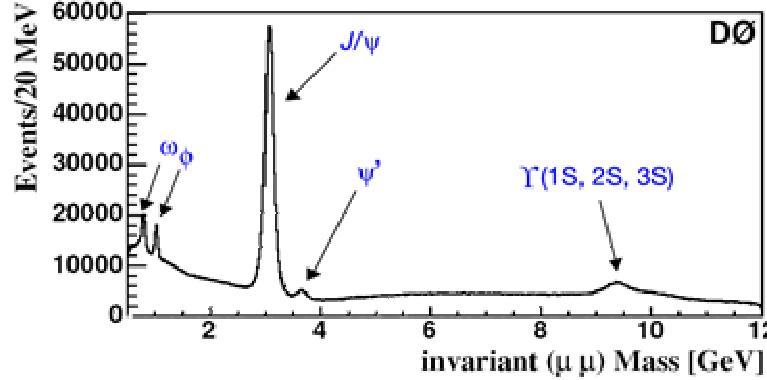
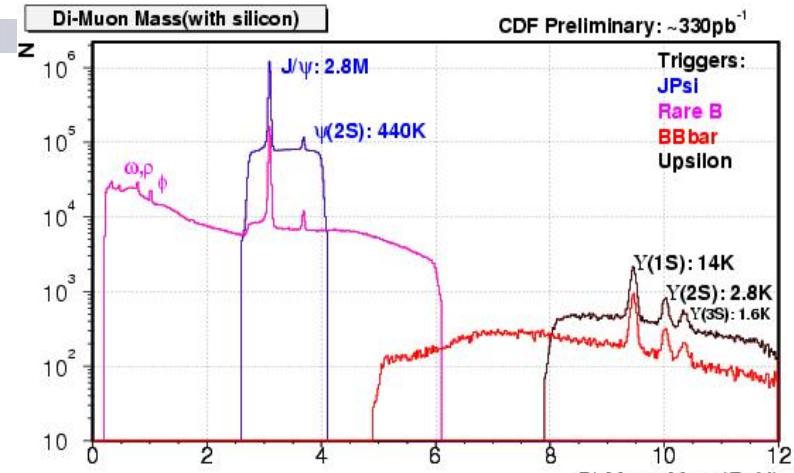
- A high p_T lepton or two leptons with lower p_T
- J/ ψ modes, masses, lifetimes, x-section
- Yields higher than Run I (low Pt threshold, increased acceptance)

lepton + displaced track - semileptonic sample (CDF)

- $p_T(e/\mu) > 4 \text{ GeV}/c$, $120 \mu\text{m} < d0(\text{Trk}) < 1\text{mm}$, $p_T(\text{Trk}) > 2 \text{ GeV}/c$
- Semileptonic decays, lifetimes, flavor tagging
- B Yields 3x Run I

Two displaced vertex tracks - hadronic sample (CDF)

- $p_T(\text{Trk}) > 2 \text{ GeV}/c$, $120 \mu\text{m} < d0(\text{Trk}) < 1\text{mm}$, $\Sigma p_T > 5.5 \text{ GeV}/c$
- X-section, branching ratios, B_s mixing...



Interests in B Hadron Lifetimes

C. Tarantino,
hep-ph/0310241

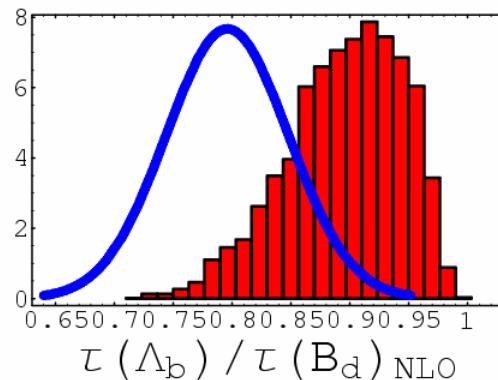
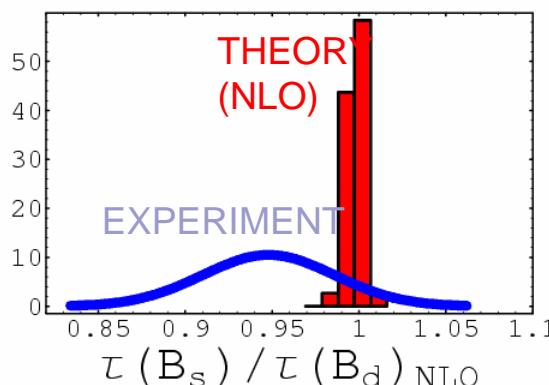
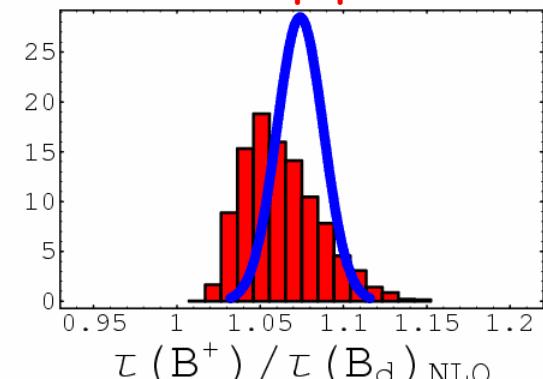
- Test of non-spectator effects in decays of heavy hadrons which give rise to lifetime hierarchy:

$$\tau(B^+) \geq \tau(B^0) \approx \tau(B_s^0) > \tau(\Lambda_b) \gg \tau(B_c)$$

- Heavy Quark Expansion includes these effects (expansion in $1/m_b$) and predicts lifetime ratios:

- $\tau(B^+)/\tau(B^0) = 1.00 \pm 0.05 \times (f_B/200 \text{ MeV})^2$
- $\tau(B_s^0)/\tau(B^0) = 1.00 \pm 0.01$
- $\tau(\Lambda_b)/\tau(B^0) \sim 0.9$

- The B^+, B^0 lifetimes are precisely measured at B-factories. Λ_b and B_s^0 ratios are unique to Tevatron.



B_s Lifetime Difference

B_s has a large branching fraction to CP eigenstates

Dominated by $b \rightarrow c\bar{c}s$ transition: $B_s \rightarrow D_s^{(*)+}D_s^{(*)-}$

(*Bd: $b \rightarrow c\bar{c}\bar{d}$ Cabibbo suppressed, 20x smaller*)

SM prediction: $\Delta\Gamma_s/\Gamma_s = \Gamma_L - \Gamma_H = (9.3 \pm 4.6) \%$ (*Beneke et al*)

hep-ph/0012222

World average: $\Delta\Gamma_s/\Gamma_s = 0.07^{+0.09}_{-0.07}$ (< 0.29 at 95% CL)

(*SLD, LEP, CDF I results + $\tau(B_s) = \tau(B_d)$ constraint*)

Ways to measure:

- Compare $\tau(B_s \rightarrow \text{CP even})$ to $\tau(B_s \rightarrow \text{CP mixed or CP odd})$
Angular analysis of $B_s \rightarrow J/\psi \phi$ separates CP even and CP odd.
[See the talk by Avdhesh Chandra]
- Indirect: Measure Br ($B_s \rightarrow D_s^{(*)+}D_s^{(*)-}$) , $\tau_L(B_s \rightarrow K^+ K^-)$



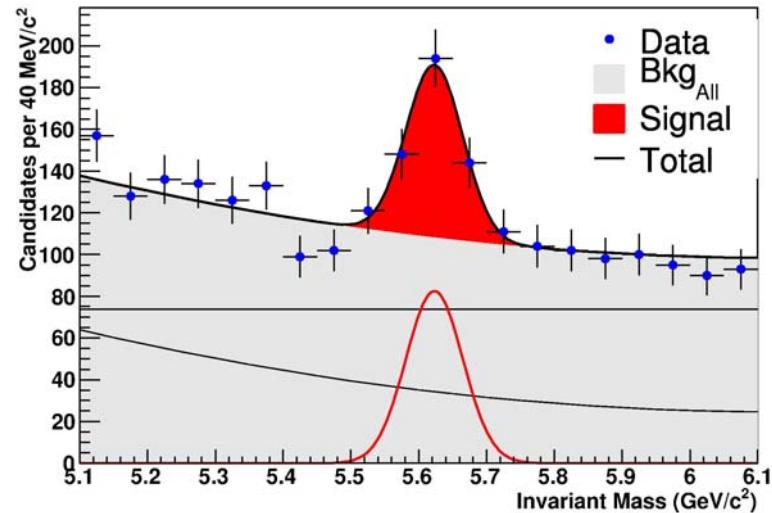
Λ_b Lifetimes

Λ_b Lifetime in $\Lambda_b \rightarrow J/\Psi \Lambda$



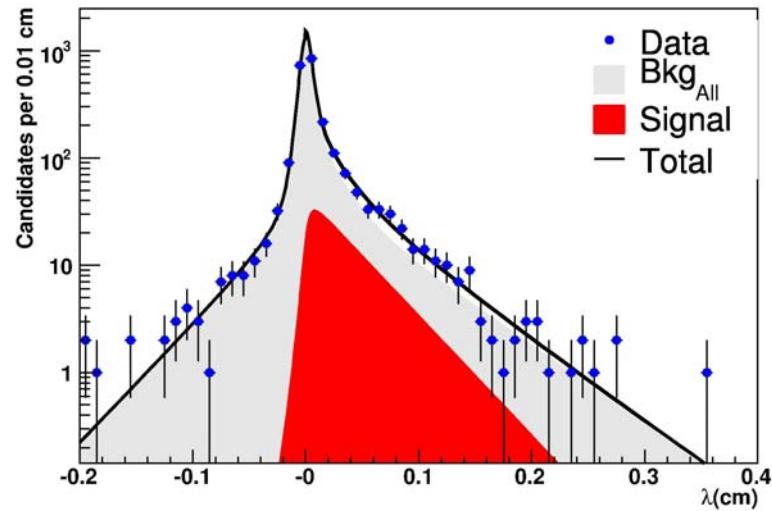
- ⊕ 1 fb^{-1} data
- ⊕ $174 \pm 21 \Lambda_b$ events
- ⊕ Extract lifetime by an unbinned maximum likelihood fit to mass and proper decay length.

$$\tau(\Lambda_b) = 1.298 \pm 0.137 \text{ (stat)} \pm 0.050 \text{ (syst)} \text{ ps}$$



- ⊕ Major source of systematic is contamination from B^0
- ⊕ Using $B^0 \rightarrow J/\Psi K_s^0$ lifetime:

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.870 \pm 0.102 \text{ (stat)} \pm 0.041 \text{ (syst)}$$



Λ_b Lifetime in $\Lambda_b \rightarrow J/\Psi \Lambda$

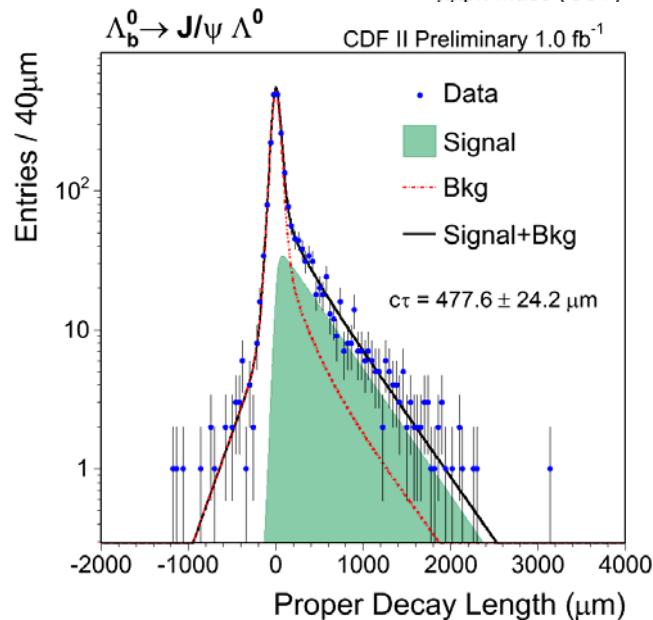
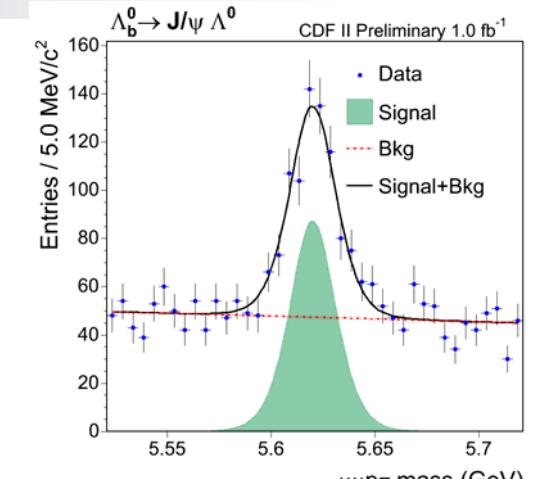
- 1 fb^{-1} data
- $538 \pm 38 \Lambda_b$ events

$$\tau(\Lambda_b) = 1.593^{+0.083}_{-0.078} \text{ (stat)} \pm 0.033 \text{ (syst)} \text{ ps}$$

- Major sources of systematics are due to modeling of $c\tau$ resolution and V^0 pointing
- Using world average $B^0 \rightarrow J/\Psi K_s^0$ lifetime:

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 1.041 \pm 0.057 \text{ (stat + syst)}$$

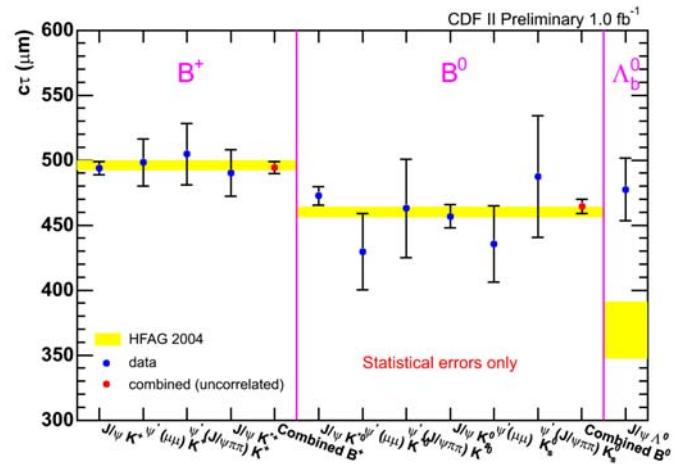
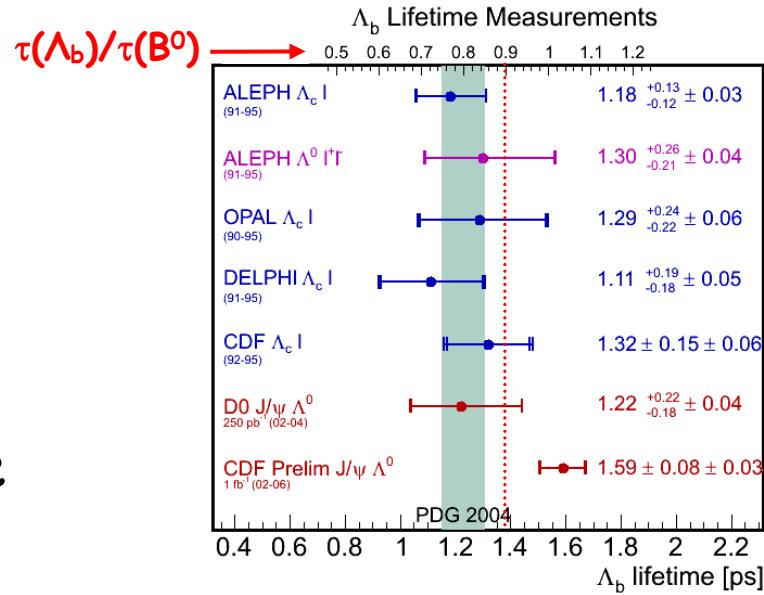
World best measurement!

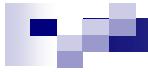


Λ_b Lifetime - Measurement vs Theory



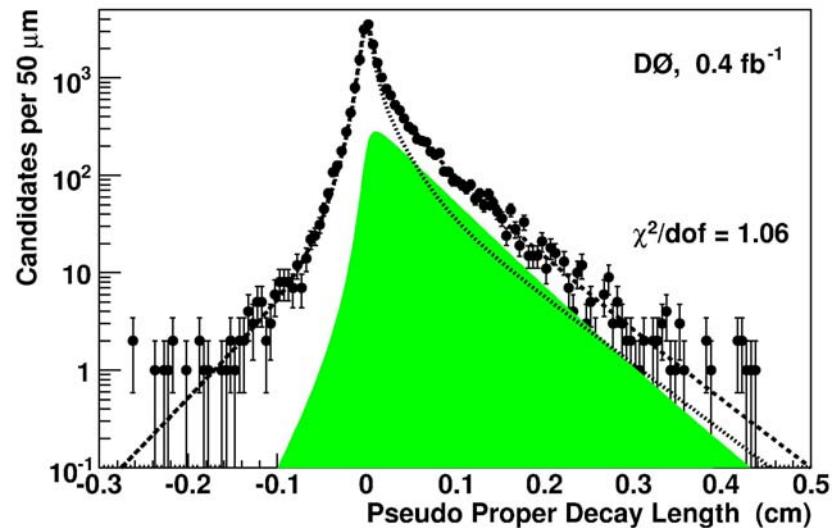
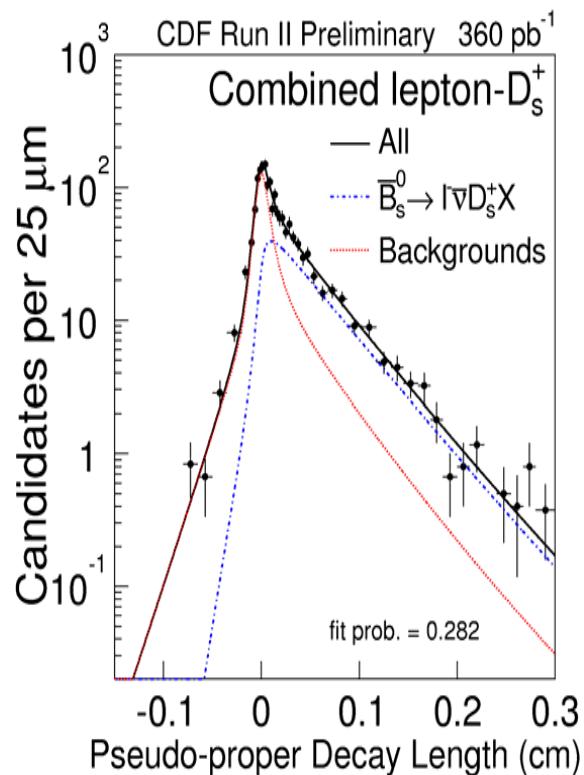
- ⊕ The world average on $\tau(\Lambda_b)/\tau(B^0)$ measurements used to show $\sim 2\sigma$ lower value than the NLO prediction so far.
- ⊕ The new result sits above the prediction!
- ⊕ Need more experimental inputs to conclude the issue.
- ⊕ Looking forward to $\tau(\Lambda_b)$ in fully hadronic decay modes, e.g. $\Lambda_b \rightarrow \Lambda_c \pi$.





B_s Lifetime Differences

B_s Lifetime $\tau(B_s \rightarrow D_s \ell \nu X)$



360 pb^{-1}

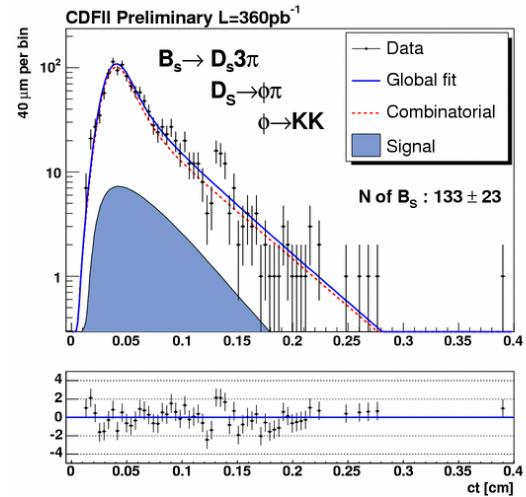
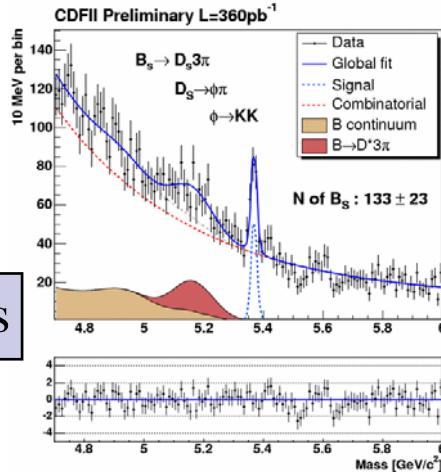
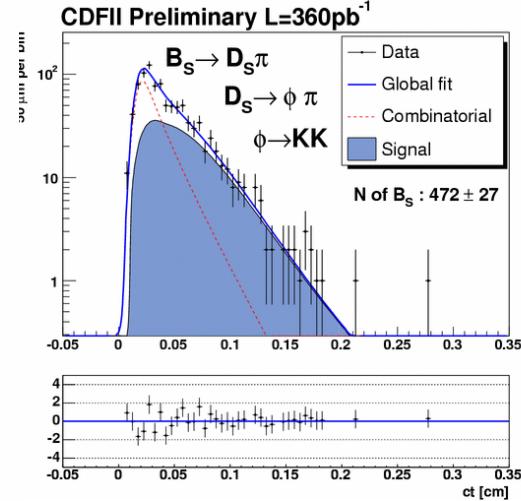
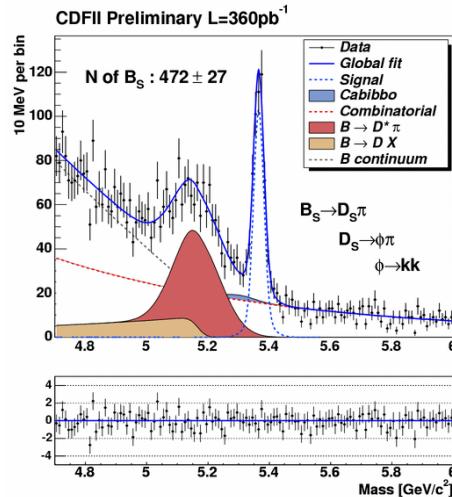
$$\tau_{B_s^0} = 1.381 \pm 0.055 \text{ (stat)} {}^{+0.052}_{-0.046} \text{ (syst)} \text{ ps} \quad \left| \quad \tau_{B_s^0} = 1.420 \pm 0.043 \text{ (stat)} \pm 0.057 \text{ (syst)} \text{ ps} \right.$$

B_s Lifetime $\tau(B_s \rightarrow D_s \pi, 3\pi)$



- Fully reconstructed hadronic decays from displaced track trigger
- 360 pb^{-1} in CDF Run 2.
- Trigger bias is removed by a Monte Carlo approach.
- Mass and decay length fitted simultaneously to extract lifetime.
- Would be updated for 1 fb^{-1}

$$\tau(B_s^0) = 1.60 \pm 0.10 \text{ (stat)} \pm 0.02 \text{ (syst)} \text{ ps}$$



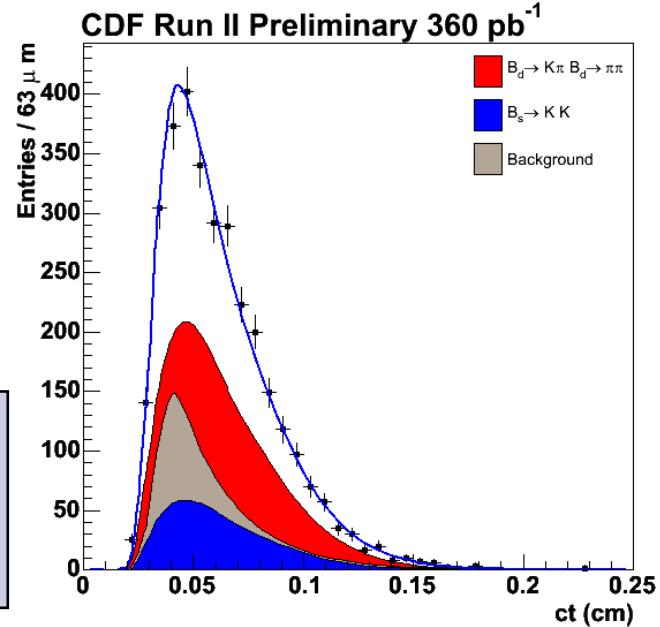
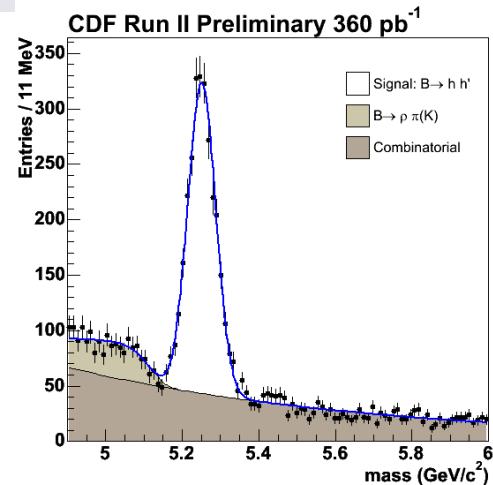
$\Delta\Gamma_{CP}/\Gamma_{CP}$ in $\tau_L(B_s \rightarrow K^+ K^-)$



- ⊕ Measure τ_L (95% CP even state)
- ⊕ 360 pb⁻¹ data from displaced track trigger
- ⊕ Four h^+h^- components are resolved by mass, kinematics and PID info.
- ⊕ B_d lifetime is fixed to world average
- ⊕ Dominant systematics from dE/dx based PID, MC p_T input spectrum
- ⊕ Extract $\Delta\Gamma_{CP}/\Gamma_{CP}$ using flavor specific $\tau(B_s^0)$ from other measurements.

$$\tau(B_s^0 \rightarrow K^+ K^-) = 1.53 \pm 0.18 \text{ (stat)} \pm 0.02 \text{ (syst)} \text{ ps}$$

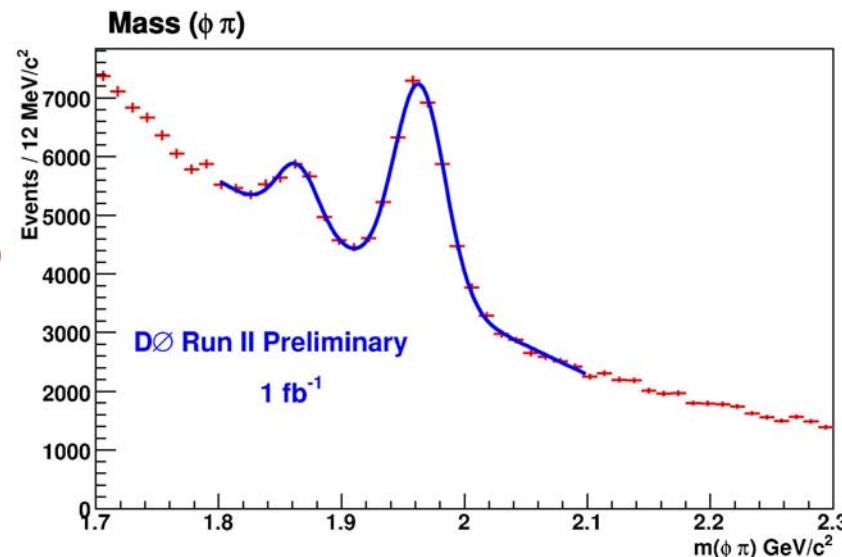
$$\frac{\Delta\Gamma_{CP}}{\Gamma_{CP}} = -0.08 \pm 0.23 \pm 0.03 \quad (\text{using } \tau(B_s)_\text{fs} \text{ from world avg.})$$



$\Delta\Gamma_{CP}/\Gamma_{CP}$ in $BR(B_s \rightarrow D_s^{(*)} D_s^{(*)})$



- ⊕ 1 fb^{-1} sample
- ⊕ $D_s \rightarrow \phi\pi, D_s \rightarrow \phi\mu\nu, (\phi \rightarrow K^+ K^-)$
- ⊕ Start with μD_s sample ($D_s \rightarrow \phi\pi$), look for additional ϕ ($\mu D_s \phi$ sample)
- ⊕ Ratio of efficiencies estimated using simulated events.
- ⊕ Directly fit D_s mass distribution to extract $N(\mu D_s)$. Unbinned likelihood to extract $N(\mu\phi D_s)$ (Lower statistics)
 - ⊕ $N(\mu D_s) = 15225 \pm 310$
 - ⊕ $N(\mu\phi D_s) = 19.3 \pm 7.9$

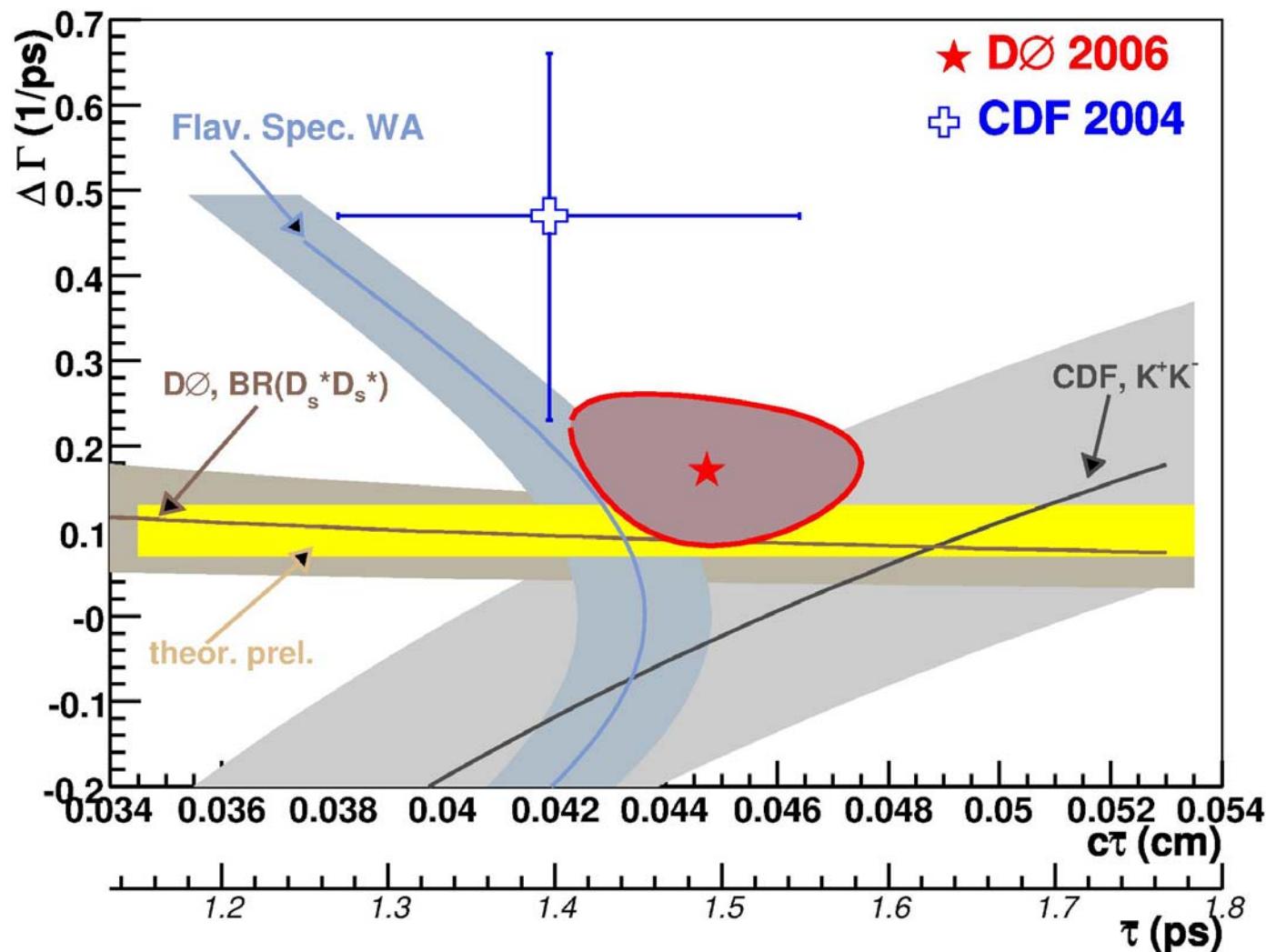


- ⊕ Dominant sources of systematics:
 - ⊕ $BR(B_s \rightarrow \mu\nu D_s^{(*)})$
 - ⊕ MC p_T reweighting

$$BR(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)}) = 0.071 \pm 0.032(\text{stat})^{+0.029}_{-0.025}(\text{syst})$$

$$\frac{\Delta\Gamma_{CP}}{\Gamma}(B_s^0) = 2 \times BR = 0.142 \pm 0.064(\text{stat})^{+0.058}_{-0.050}(\text{syst})$$

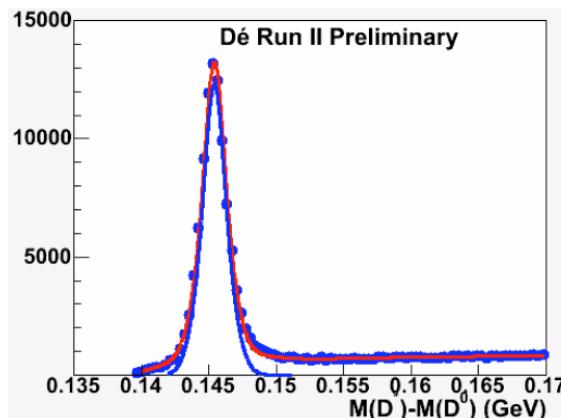
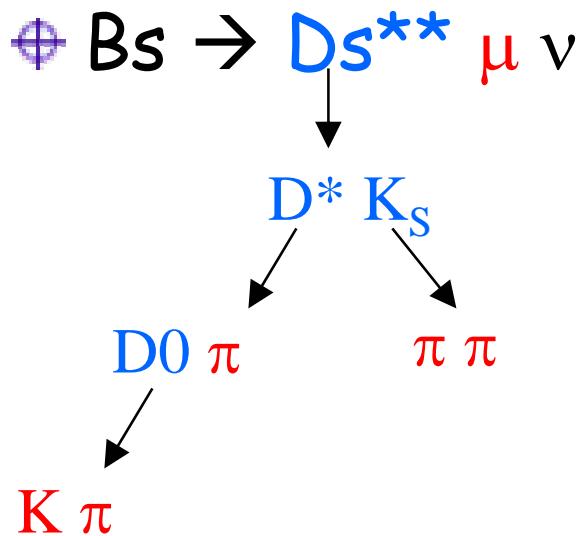
Tevatron $\Delta\Gamma_{CP}/\Gamma_{CP}$ Summary





B_s Branching Fractions

$B_s \rightarrow D_{s1}(2536) \mu^+ \nu X$

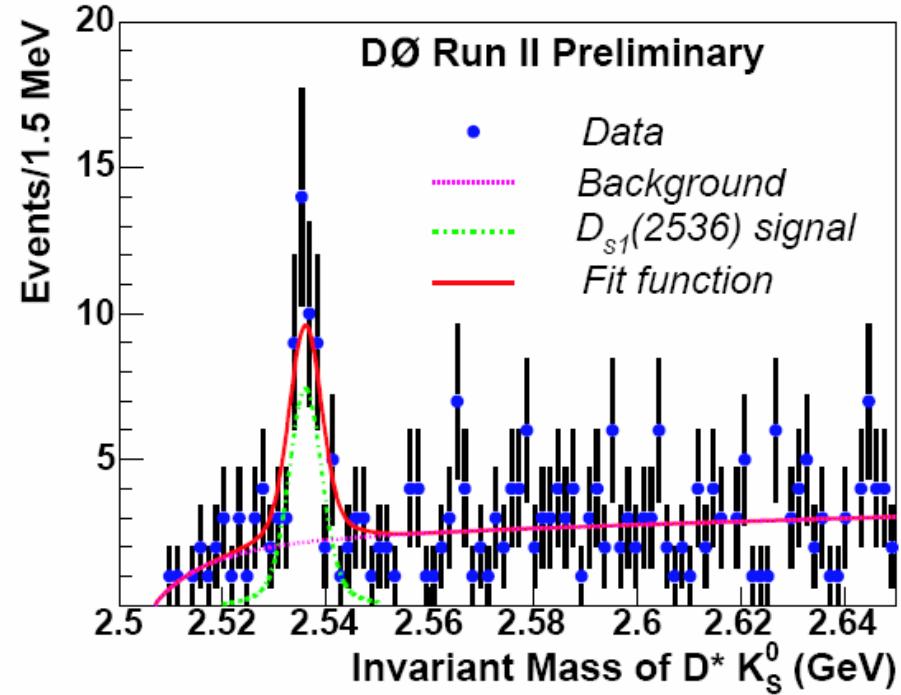


- ⊕ c+s quark in L=1 state : Provide test HQET
- ⊕ A significant fraction of semileptonic decays :
 - ✓ Compare exclusive/inclusive decay rates
 - ✓ Extract CKM matrix elements
 - ✓ An additional channel for B_s mixing.
- ⊕ Need to develop more understanding in the light of discoveries which don't agree with predictions : $D_s J(2317)$, $D_s J(2460)$, $D_s J(2632)$ - SELEX and so on...

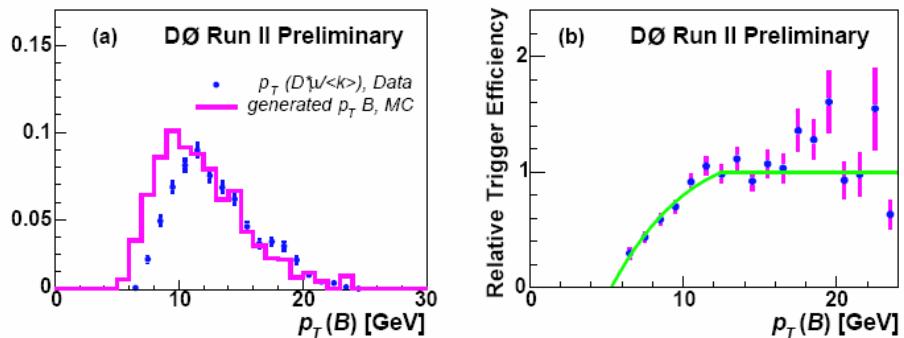
$B_s \rightarrow D_{s1}(2536) \mu^+ \nu X$ (*Contd..*)

$$f(\bar{b} \rightarrow B_s^0) \cdot Br(B_s^0 \rightarrow D_{s1}(2536)\mu^+\nu X) \cdot Br(D_{s1}(2536) \rightarrow D^{*-}K_S^0) =$$

$$Br(\bar{b} \rightarrow D^{*-}l^+\nu X) \cdot \frac{N_{D_{s1}(2536)}}{N_{D^*\mu}} \cdot \frac{1}{R_{D^*\mu}^{gen} \epsilon_{D_{s1}(2536)}}$$



$$R_{D^*}^{gen} = \epsilon(\bar{B}_s^0 \rightarrow D_{s1}\mu \rightarrow D^*\mu) / \epsilon(\bar{b} \rightarrow D^*\mu)$$



$$f(\bar{b} \rightarrow B_S^0) Br(B_S^0 \rightarrow D_{s1}^- \mu^- \nu X) Br(D_{s1}^- \rightarrow D^{*-} K_S^0) =$$

$$(1.8 \pm 0.4(stat) \pm 0.3(syst)) \times 10^{-4}$$

Comparison with theory

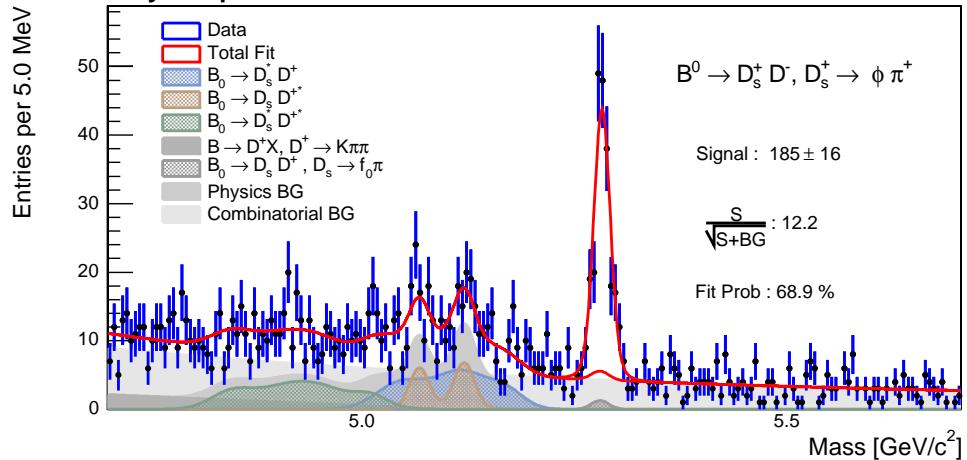
$N = 42.6 \pm 8.6 \sim 5 \sigma$

$BR(B_s \rightarrow D_{s1}\mu\nu X) = 0.86 \pm 0.16 \pm 0.13 \pm 0.09 (\%)$
ISGW2 0.53%, IQM 0.39%, HQET&QCD Sum rules 0.20%

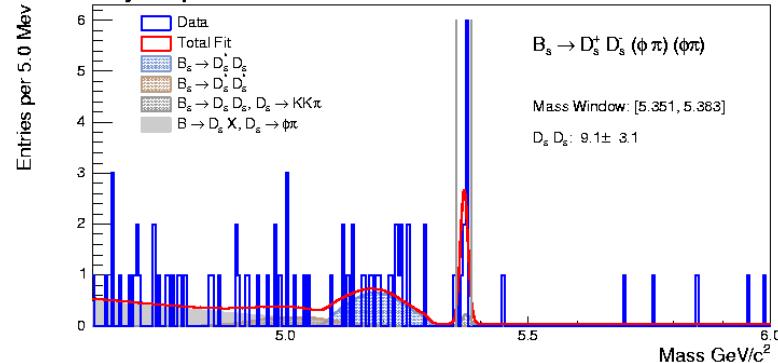
$\text{BR}(\text{B}_s \rightarrow \text{D}_s \text{ D}_s) / \text{BR}(\text{B}^0 \rightarrow \text{D}_s \text{ D}^-)$



CDF Preliminary 355 pb⁻¹



CDF Preliminary 355 pb⁻¹



5.8 σ Observation!

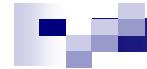
$$f_s/f_d * \text{BR}(\text{B}_s \rightarrow \text{D}_s \text{D}_s) / \text{BR}(\text{B}^0 \rightarrow \text{D}_s \text{D}^+) = 0.43 \pm 0.11(\text{Stat}) \pm 0.03(\text{Syst}) \pm 0.10(\text{BR})$$

$$\text{BR}(\text{B}_s \rightarrow \text{D}_s \text{D}_s) / \text{BR}(\text{B}^0 \rightarrow \text{D}_s \text{D}^+) = 1.67 \pm 0.41(\text{Stat}) \pm 0.12(\text{Syst}) \pm 0.24 (\text{fs/fd}) \pm 0.39(\text{BR})$$

Summary

- ⊕ With over 1 fb^{-1} accumulated data / experiment and much more to come, heavy flavor physics at Tevatron is entering a precision era.
- ⊕ Using large B_s and Λ_b samples, unique to Tevatron, various theoretical predictions are put to stringent tests. Many world best measurements have been made.
- ⊕ Lifetimes in fully hadronic Λ_b decays are underway. Other excited baryonic modes to follow.
- ⊕ Check out more Tevatron B physics results:
 - ⊕ **CDF:** <http://www-cdf.fnal.gov/physics/new/bottom/bottom.html>
 - ⊕ **DØ:** <http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm>

Backup-1 $\Delta\Gamma_{CP}/\Gamma_{CP}$ in $BR(B_s \rightarrow D_s^{(*)} D_s^{(*)})$

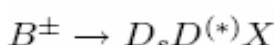


$$\frac{N(\mu\phi D_s) - N_{bkg}(\mu\phi D_s)}{N(\mu D_s) f(B_s^0 \rightarrow \mu\nu D_s^{(*)})} = \frac{2 \text{ Br}(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)}) \cdot \text{Br}(D_s \rightarrow \phi\mu\nu)}{\text{Br}(B_s^0 \rightarrow \mu\nu D_s^{(*)})} \text{ Br}(\phi \rightarrow K^+ K^-) \frac{\varepsilon(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)})}{\varepsilon(B_s^0 \rightarrow \mu\nu D_s^{(*)})}$$

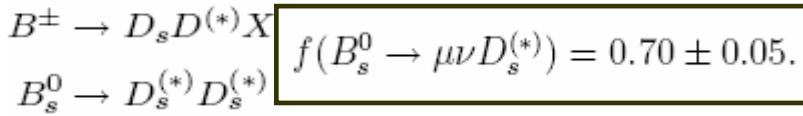
Background processes:



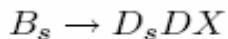
$B_s^0 \rightarrow D_s^{(*)} D_s^{(*)}$ - the main process;



$B \rightarrow D_s^{(*)} D_s^{(*)} K X$ - double- D_s decay of ordinary B mesons



$B_s^0 \rightarrow D_s^{(*)} D_s^{(*)} X$ - multi-body double charm decays;



$B_s^0 \rightarrow \mu\nu D_s^{(*)} \phi$;
 $c\bar{c} \rightarrow \mu\phi D_s^{(*)}$;

$N_{bkg}(\mu\phi D_s) = 1.7 \pm 1.2.$